[3] Iridell and Minett, "Notes of the Effect of Radium in Relation to Some Pathogenic and Non-Pathogenic Organisms," *Lancet*, 1909, **1**, p. 1445.

[4] Lequeux and Chrome, "Action of Radium on Bacteria," *Arch. Memo. Obst. gynec.*, **3**, p. 698, Dec. 1919.

THE JADES OF MIDDLE AMERICA[1]

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Communicated October 4, 1922

The following pages present some of the results of a study of jade beads, disks, and other small objects, found in a *cenote*, or sacred natural well, at the ancient Maya city of Chichen Itza, in northern Yucatan, the petrographic study of which was kindly entrusted to me by Prof. A. M. Tozzer of Harvard University. The final results will be incorporated in a forthcoming archaeological monograph on the contents of the cenote, under the editorship of Prof. Tozzer. In connection with this study, I have also been able to examine some ancient Mexican beads, through the kindness of Dr. L. Salazar, Director of the Geological Survey of Mexico, and some jade objects from Copan, Honduras, which were kindly placed at my disposal by Dr. Sylvanus G. Morley. I am deeply indebted to Dr. H. E. Merwin, of this Laboratory, for numerous optical determinations.

There is great variety in all the characters, chemical, mineral, and physical, of the Chichen Itza and other American jades. There are two dominant colors: green and gray. Some objects are wholly of a deep, rather yellowish green, like Ridgway's "pistachio green," or of a grayish green, like Ridgway's "pea green," the first being used for the choicest objects. The grays vary from almost pure white, through ash-, gull-, and dove-gray, to rather dark gray, most of the gray specimens being mottled in lighter and darker shades. Another and common type is mottled white (or very light gray) and a clear, bright, grass-, or emerald-green. A few obsidian beads were also found at Chichen Itza.[2]

The texture varies from decidedly coarse-grained, as are most of the pistachio-green and mottled green and white specimens, to very fine grained, as are most of the pea-green specimens; the gray specimens are mostly moderately fine-grained. The coarse-grained pieces show glistening cleavage surfaces of pyroxene on the fracture. Nearly all these objects have a high to very high polish, which is most marked on the coarser and the pistachio-green varieties. The coarse varieties are rather translucent, as are some of the fine-grained pea-green beads; the whites and grays are generally opaque.

A few beads are dead white, of dull luster, and slightly crumbly. These have evidently been subjected to the action of fire, and the effect of this is clearly seen in one or two long beads which have been heated to the point of softening, so that they are bent and warped to such an extent that the longitudinal perforation is no longer straight.

The coarse-grained, translucent, green or green and gray varieties have a hardness of about $6^3/_4$, while the mottled gray and white kinds are about $6^1/_2$. None of this American jade shows the extreme toughness which is so characteristic of most jade, especially nephrite.

Many density determinations have been made, representing the various color and textural varieties, from Chichen Itza, Copan, and Mexico. The density varies from 3.335, about that of pure jadeite, to 2.667, about that of oligoclase. Some characteristic densities are given later. The numerous determinations by Hallock, published by Clarke and Merrill,[3] also show the wide variation in density.

In thin section most of the coarser specimens, whether wholly green, mottled green and white, or wholly white or gray, are seen to be composed entirely of anhedral or subhedral grains of pyroxene, no other mineral being present. The pyroxene grains are somewhat cracked, but there is little other evidence of crushing. The megascopically white and gray material is perfectly clear and colorless, while the green specimens, and the green portions of those which are mottled, are of a light, slightly yellowish green, with slight pleochroism. The green color is obviously not caused by the aegirite molecule. In the green-white mottled specimens, the color is distributed like a stain, covering small irregular areas, and fading out gradually in all directions, so that some grains near the border are partly green and partly colorless. In some pieces the green color is seen megascopically to be deeper along fine cracks, indicating the presence of a chromium-bearing solution. The purely pyroxenic specimens, it may be said, are those of the higher densities.

In other specimens, of the lower densities, and chiefly among the mottled green and white, mottled white and gray, and the fine-grained light pea-green varieties, there is more or less feldspar, which appears as a water-clear albite, in irregular interstitial areas or a granular mass. This albite very rarely shows twinning. The relative amount of albite (or oligoclase) varies within wide limits, from a few shreds and patches to the greater part of the section. As the amount of albite increases the pyroxene grains become smaller, more prismatic, and more scattered, until in the most albitic specimens the small percentage of pyroxene forms small prisms scattered through a matrix of albite grains.

Apart from the pyroxene and albite, no other minerals are present,

except for a very few small shreds of muscovite and an occasional very minute magnetite grain.

The pyroxene is of very variable composition, but is composed essentially of jadeite and diopside, the proportions of which vary within wide limits, from jadeite : diopside = 21 : 1 in No. 6, to about equal amounts in the Tuxtla statuette,[3] and even 1 : $2^1/_2$ in the Copan pebble.[4] Jadeite can evidently take up considerable amounts of diopside in solid solution. The material of the Tuxtla statuette, with about equal amounts of each, may be regarded as an end member of the series, and for this the name *tuxtlite* (pronounced tushtlite) is proposed. It may be a double salt, analogous to diopside or dolomite. Its optical characters (as determined by Merwin) are given in the paper cited, as well as its density (determined by Adams) and its chemical composition. From the data given later in table I, it would appear that the diopside-jadeite can take up albite and anorthite in solid solution to a certain extent, although according to Bowen,[5] there is no experimental evidence of the solution of plagioclase in typical diopside, $CaMgSi_2O_6$.

Some of the chemical analyses made by me of various Middle American jades, with two made by other analysts, are presented in table I. The densities and the optical properties of the pyroxene were determined on the same fragment which was used for the analysis. For the optical determinations I am deeply indebted to Dr. H. E. Merwin. With each analysis is given the composition calculated in terms of the four molecules: jadeite, diopside (including in some cases very small amounts of hypersthene, or wollastonite and a little excess ferric oxide), albite (including minute amounts of orthoclase), and anorthite. After allotting alumina to potash and soda, the invariable small excess was allotted to lime in anorthite. Diopside was then calculated, the usual slight excess of magnesia and ferrous oxide over lime forming very small amounts of hypersthene. The residual silica was, in every case, more than enough to form jadeite and less than enough to form albite; so it was distributed between these two molecules by the usual equations used in calculating the norm.

The first five specimens are shown by the microscope to be quite monomineralic, composed entirely of pyroxene, and without any feldspar, although No. 5 shows a very few small shreds of muscovite. The section of No. 6 shows a little albite, in small interstitial grains; and from this on to No. 12 (inclusive) the amount of visible albite steadily increases. The jade of the Copan pebble differs markedly from the others, in texture and composition of the pyroxene; it has been described elsewhere.[4] No. 13 is the analysis of a small bead given me by Dr. Salazar, which is remarkable as being related to nephrite. It is composed of a densely felted mixture of pyroxene and zoisite, the latter as determined by Merwin.

TABLE I

ANALYSES OF MIDDLE AMERICAN JADES

	1	2	3	4	5	6	7	8	9	10	11	12	13
SiO_2	55.50	58.70	57.92	59.03	59.80	59.93	59.60	60.99	63.47	64.64	62.64	67.16	46.00
Al_2O_3	12.33	22.55	19.74	23.26	21.79	23.38	21.85	22.20	20.76	18.83	14.92	18.81	18.64
Fe_2O_3	1.41	0.48	1.08	0.41	0.20	0.44	0.48	....	1.27	0.46	0.60	0.27	0.92
FeO	1.33	0.53	0.48	0.42	0.66	0.41	0.58	0.65	.....	0.49	1.25	0.32	2.24
MgO	8.72	2.14	3.34	1.31	2.25	0.71	2.57	0.96	1.11	1.87	4.31	0.57	11.09
CaO	12.76	3.07	4.67	0.92	2.50	1.07	3.29	1.28	1.16	2.62	5.92	1.33	17.49
Na_2O	6.94	12.87	11.28	13.31	12.50	13.34	11.78	13.04	11.98	11.25	8.78	11.21	0.64
K_2O	0.25	0.15	0.25	0.31	0.27	0.29	0.20	0.21	0.34	0.23	0.23	0.22	0.08
H_2O+	0.10	0.12	0.80	0.65	0.32	0.42	.....	0.74	0.36	0.16	1.27	0.14	2.38
H_2O-	0.20	.....	....	0.09	.....	0.21	.....	....	.....	.....	....	.....	0.21
TiO_2	none	none	none	none	0.02	none	none	n.d.	n.d.	none	none	none	0.05
Cr_2O_3	none	0.08	0.17	0.26	0.05	0.09	.....	n.d.	n.d.	0.07	none	none	....
MnO	0.05	none	none	none	none	none	none	n.d.	trace	none	none	none	trace
	99.59	100.69	99.73	99.97	100.36	100.29	100.35	100.07	100.45	100.46	99.92	100.02	99.74
Sp. gr.	3.270	3.183	3.312	...	3.052	3.237	3.196	....	2.832	2.737	2.934	2.667	3.161
C°	....	17.9°	19.2°	...	23.9°	21.3°	22.8°	....	....	23°	19.4°	24.4°	24.4°
Jd	45.15	81.69	65.93	78.11	70.50	73.06	62.24	64.45	40.55	25.15	10.25	4.05	....
Di	51.51	11.54	18.72	5.27	11.58	3.48	12.01	5.60	6.64	11.10	25.78	4.80	....
Ab	1.67	3.45	12.54	13.82	15.44	20.10	19.65	28.27	51.14	63.47	63.40	90.87	....
An	1.67	3.32	2.81	2.80	2.48	3.36	6.10	1.68	1.67	0.28	0.57	0.28	....

1. Tuxtlite. Tuxtla statuette. Coarse-grained; pea-green. Washington analyst. *Proc. U. S. Nat. Mus.*, **60**, Art. 14, 1922 (5).
2. Chichen Itza. Spheroidal bead; coarse, dull white. Washington analyst.
3. Chichen Itza. Spherical bead; coarse, mottled green and white. Washington analyst.
4. Chichen Itza. Flat bead; coarse, mottled green and white. Washington analyst.
5. Chichen Itza. Long, cylindrical bead; mottled gray and green. Washington analyst.
6. Chichen Itza. Long, prismatic bead; coarse, light gray. Washington analyst.
7. Chichen Itza. Spheroidal bead; very coarse, mottled dark gray and green. Washington analyst.
8. "Jadeite," Mexico. Color ? G. W. Hawes analyst. Dana, *System of Mineralogy*, 1892, p. 370, No. 22.
9. "Jade," Mexico. Green and gray. P. T. Walden analyst. Penfield in Bishop, Jade Book, Vol. I, 1906. MgO given as 11.11 "Albite present."
10. Chichen Itza. Cylindrical bead; fine-grained, gray-green. Washington analyst.
11. Copan. Worked pebble; coarse, light pea-green. Washington analyst. *Jour. Wash. Acad.*, **12**, 1922 (p. 390).
12. Techalquilla, Mexico (from Guerrero?). Small triangular bead; fine-grained, tea-green. Washington analyst.
13. "Nephrite?" Atzacapotzalco, Mexico (from Guerrero?). Spheroidal bead; mottled sage- and tea-green. Washington analyst.

The general absence of titanium and manganese is to be noted, while chromium is present in easily determinable amounts in all the specimens in which it was looked for, except No. 1. Considerable chromium is present in some of the purely gray specimens, as No. 6), which shows no trace of green color.

The analyses are arranged in the order of decreasing pyroxene (diopside-jadeite) and increasing feldspar. The density varies quite regularly with this, but it is also influenced by the amount of jadeite relative to diopside in the pyroxene, those higher in jadeite showing the higher density. The relative amounts of jadeite and diopside vary widely and without any very marked regularity.

The refractive indices of some of the pyroxenes, determined by Dr. Merwin, are given in table II In this the relative amounts of jadeite and diopside (calculated to 100%) are given, the amount of albite (and anorthite) held in solid solution in the pyroxene being neglected. The serial progression in the values for α and γ as well as for the birefringence $\gamma - \alpha$,[6] as the pyroxene changes from nearly pure jadeite to pure diopside, is evident. There are slight irregularities at the extremes, and it would appear that the influence of the "occult" albite is simply to lower the refractive indices. This matter is to be studied further by Merwin and me.

TABLE II

REFRACTIVE INDICES OF THE DIOPSIDE-JADEITE SERIES

	Jd	Di	α	γ	$\gamma - \alpha$
Jadeite (Tibet)[7]	98.68	1.32	1.655	1.667	0.012
Chichen Itza (No. 6)	95.45	4.55	1.651	1.667	0.016
Chichen Itza (No. 4)	93.69	6.31	1.650	1.668	0.018
Chichen Itza (No. 2)	87.62	12.38	1.655	1.672	0.017
Chichen Itza (No. 3)	77.89	22.11	1.660	1.678	0.018
Tuxtla (No. 1)	46.60	53.40	1.666	1.688	0.022
Copan pebble (No. 11)	28.45	71.55	1.665	1.693	0.028
Diopside (artificial)[8]	none	100.00	1.664	1.694	0.030

The feldspars show much less variation, which is not quite regular, but in general the feldspar becomes more albitic with increase of the amount of feldspar in the specimen. From what has been said, it is evident that the pyroxene of the wholly pyroxenic specimens contains considerable "occult" feldspar, both albite and anorthite, held in solid solution. No. 5 shows no feldspar in the thin section, although about 18% of $Ab_{86}An_{14}$ must be calculated as present. No. 6, however, which contains about 23.46% of similar normative feldspar, shows a few per cent present in the section. From a somewhat cursory study of the sections of the analysed specimens from this on to No. 12, it appears that the amount of visible (modal) feldspar is uniformly less than the calculated

amount. It would seem, therefore, that the limit of solubility of albite (with a little anorthite) in diopside-jadeite is somewhat less than 20% by weight of the mixture. Further study of this somewhat interesting point is being undertaken.

The normative mineral relations of the Middle American jades are shown in the accompanying figure 1, in which the apices are the points for 100% (by weight, not molecular) of albite (including anorthite), jadeite, and diopside; the loci are those of the specimens whose analyses are given in

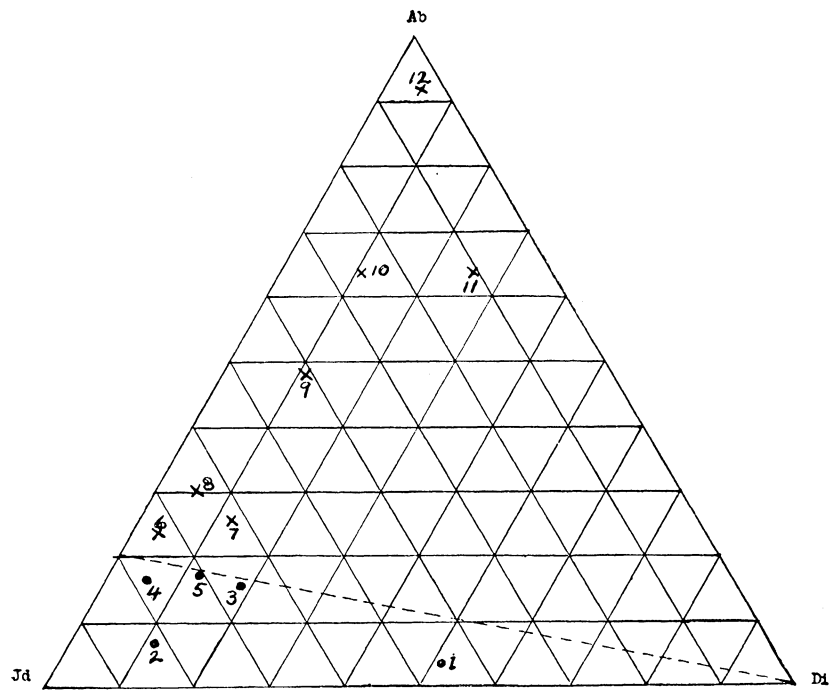

FIGURE 1
Mineral composition of jades

table I (except No. 13). There appears to be a marked tendency to cluster about the general composition: 70 jadeite, 10 diopside, 20 albite; and the greater number are strung along and rather near the albite-jadeite side. It is noteworthy that none of them fall on this border line, indicating the constant presence of diopside; while two fall almost on the line of equal amounts of jadeite and diopside, and only one (the Copan pebble) falls well within the dominantly diopside-albite part of the triangle.

In figure 1 the jades without visible feldspar are indicated by dots, while those with feldspar visible in the section are shown by crosses. The areas

of the two are separated by a dashed line, which extends from the diopside apex (on the basis of Bowen's experimental observation that typical diopside is incapable of holding feldspar in solution), to a point on the Ab-Jd border, at about 80 Jd–20 Ab. Some other analyses might have been plotted, which harmonize with those shown. The straightness and exact position of the dividing line are somewhat conjectural, but more jades which appear to fall near it, are being studied chemically and optically, so as to determine its position more accurately.

This series of rocks belongs evidently to the general group of jadeite jades, but differs from the usual jadeite of Burma and other sources of Chinese jade in two important particulars: the constant presence of large or considerable amounts of diopside with the jadeite in the pyroxene; and the presence of much albite in most of the series, either wholly in solid solution in the pyroxene, or partly so ("occult") and in part separately crystallized. The series, thus, extends from pure tuxtlite (diopside-jadeite, 1:1) to nearly pure albite. Further discussion of these points cannot be undertaken here, for lack of space; but it is suggested that this series shows such well-marked general and serial characters as to be deserving of a special name. That here proposed is *mayaite* which recalls the ancient nation who used and valued it, and which may distinguish it from the more widely known Burmese jadeite jades (with little or no diopside or albite). Purely jadeite jade seems to be unknown from, or at least is of very rare occurrence in, Middle America.

From these petrological considerations, the conclusion is inevitable that the material of the Central American and Mexican "jade" objects is of American and not Asian provenance. Although no American locality is yet known where *mayaite* occurs in situ, yet there are numerous specimens which are either clearly pebbles or show traces of pebble surfaces. But this is not the place for archaeological discussion. It may only be said, in conclusion, that various considerations regarding the occurrence of igneous rocks in different parts of the North American continent, as well as of the occurrence of Middle American jade objects, lead me to the belief that: (1) the jades come unquestionably from either Mexico or from Central America, or from both, and that (2) there are probably two centers of supply, both near the west (Pacific) coast, one probably in Oaxaca or Guerrero, and the other probably in Guatemala.

[1] The term "Middle America" is used to include both Mexico and Central America.
[2] H. S. Washington, *Proc. U. S. Nat. Mus.*, **60**, Art. 14, 1922.
[3] Clarke and Merrill, *Proc. U. S. Nat. Mus.*, **11**, 1888 (122, 124).
[4] H. S. Washington, *J. Wash. Acad. Sci.*, **12**, 1922 (387).
[5] N. L. Bowen, *Amer. J. Sci.*, **40**, 1915 (161).

[6] The birefringence, γ-α, of jadeite is uniformly given in the literature as 0.029, following apparently the early determination of Lévy and Lacroix (*Les Minéraux des Roches*, 1888 (266)). This value is certainly too high for pure jadeite, and the value 0.012, determined by Merwin on an analysed and crystallographically described crystal of pure jadeite, should replace it.

[7] Merwin, in Washington, *Proc. U. S. Nat. Mus.*, **60**, Art. 14, 1922 (9).

[8] Wright and Larsen, *Amer. J. Sci.*, **37**, 1909 (33).

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*ON A COMPARISON OF THE RELATIVE SENSITIVENESS OF TELEPHONES**

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Communicated, September 20, 1922

In the earlier papers I reduced the fringe deflections s, of the interferometer U-gauge, produced by telephone currents of different effective strength by the simple relation sr = const., where for a fixed effective voltage, the resistance r in the telephone circuit is very large compared with the inductance, etc. The telephone mouthpiece is connected with one or both shanks of the U-gauge by a quill tube, simple or branched, respectively, each branch containing a pinhole probe suitably directed. Thus s measures the acoustic pressure evoked when the telephone sounds.

The expression given is applicable only within the narrow range of s values and low frequencies for which it was used. For wider ranges an exponential relation, which may be written

$$\log s = \log s_0 - r/r_0$$

where s_0 and r_0 are constant, fits the observations as accurately as the fringes can be read. To give examples chosen at random for a single telephone, branched connection, salient and reëntrant pinholes (s_0 = 399 fringes, r_0 = 6380 ohms)

$r \times 10^{-3}$	4	5	6	7	8	ohms
s observed	95	65	45	32	22	fringes
s computed	94	65	46	32	22	fringes

and the same for low ranges of s(s_0 = 190, r_0 = 8620)

$r \times 10^{-3}$	8	9	11	14	18	ohms
s observed	22	17	10	5	1	fringes
s computed	22	17	10	5	2	fringes